

Modulation Strategies for Indirect Matrix Converter: Complexity, Quality and Performance

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Abstract—In general, there are two main classifications in matrix converters. The most common known type is conventional matrix converter (CMC) or direct matrix converter (DMC). The other type is indirect matrix converter (IMC). A brief review for modulation strategies are provided in this work for modulation methods for IMC such as carrier-based modulation and space vector modulation (SVM). A sinusoidal current waveform is produced on the input and output sides to implement the modulation method. In the conclusion the modulation methods will be compared based on performance, theoretical complexity, and some other parameters.

Keywords—AC-AC conversion, carrier-based modulation, indirect matrix converter, pulse width modulation, space vector modulation.

I. INTRODUCTION

Matrix Converter (MCs) usually is made from an AC-AC converter which includes the array bidirectional switches. This array is useful to connect main power supply to the load. At this connection circuit, there is no DC-link or energy storage elements [1]. The MCs have a great demand because of their superior function such as: (1) dc link capacitor is removed, (2) a sinusoidal waveform at both input and output terminal, (3) bidirectional power-flow capability, (4) power factor at input side is adjustable, (5) less weight and volume in design, and (6) long life usage [2], [3].

Basically, there is no limitation of frequency for MCs, however the output amplitude is limited to be smaller than input. Modulation technique can be used for solving this limitation problem [4]. There are two modulation strategies commonly used for MCs [5] namely: (1) method for carrier based modulation [6], and (2) space vector modulation (SVM) [2].

This paper briefly explains the most relevant strategies in modulation for IMC and provides the complexity and performance comparison of modulation strategies.

II. IMC WORKING PRINCIPLE

Common circuits of MCs are usually known in two types of topologies i.e. (1) the conventional matrix converter (CMC) and (2) the indirect matrix converter (IMC). The first IMC topology was proposed by Kolar et al [7], and then developed by another researcher in [8]–[12], the basic principle of IMC are constructed from bidirectional current source rectifier (CSR) and voltage source inverter (VSI) without the use of any intermediate energy storage element [13] [14], as shown in Fig. 1. Commutation in zero

current for IMC applies together with the rectifier circuit and this circuit gives lower losses during switching and reliable topology.

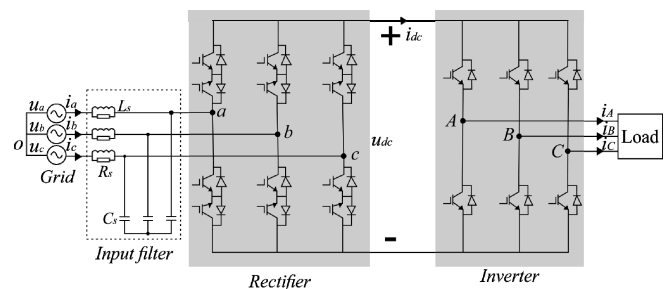


Fig. 1. Schematic diagram of IMC.

The indirect modulation separates each control on input current and output voltage side. The separation or it is also known as a decoupled strategy is carried out by decoupling transfer function T of MCs into first transfer function for rectifier and the second transfer function for inverter [15].

Where:

$$T = I * R$$

$$\begin{bmatrix} S_{aA} & S_{bA} & S_{cA} \\ S_{aB} & S_{bB} & S_{cB} \\ S_{aC} & S_{bC} & S_{cC} \end{bmatrix} = \begin{bmatrix} S_7 & S_8 \\ S_9 & S_{10} \\ S_{11} & S_{12} \end{bmatrix} \cdot \begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix} \quad (1)$$

In equation (1), inverter switches S_7 – S_{12} and rectifier switches S_1 – S_6 . Result to the product and sum of the input phases. As the equivalent circuit is observed from phase A of inverter output, then two switches S_7 and S_8 of phase A at half bridge are connected directly to phase a, b and c at input side through six switches on rectifiers [16].

III. GENERAL CLASSIFICATION OF MODULATION STRATEGIES FOR MCs

Fig. 2 shows the classification of modulation methods developed for the IMC. Basically the most well known modulation on MCs is Pulse width modulation (PWM). PWM is classified into two type of modulation strategies, i.e. carrier-based and space vector modulation (SVM) [5]. Carrier-based modulation method is the simplest approach, while the SVM method has an elegant and powerful solution for IMC. The modulation method for IMC was very interested to developed, several method was developed for IMC modulation method proposed in [6], [13], [17]–[21], [21]–[24]

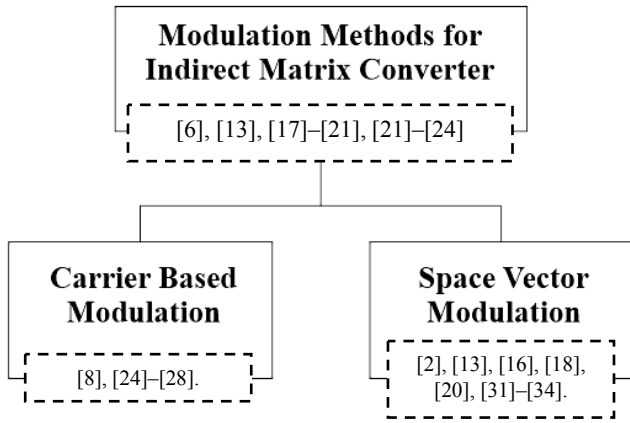


Fig. 2. Summary of modulation strategies for IMC.

IV. CARRIER-BASED MODULATION FOR IMC

The first research about carrier-based modulation for MC was proposed by Yoon *et al* [6], by changing the carrier of slope and using voltage offset. By using this techniques, synthesize product of unity power factor in sinusoidal input currents and desired output voltages is implemented. A carrier based PWM for IMC was proposed by Wang [17], where the algorithm of the carrier-based modulation is enhanced in two techniques. The first technique makes a continuous modulation function for all throws based on the designed sinusoidal input current. The switching functions are intended to focus on the zero current commutation which has derived from the modulation functions. More details about this method can be found in [17] and [25]. Different research about carrier-based modulation also proposed in [8], [24]–[28].

V. SPACE VECTOR MODULATION FOR IMC

SVM techniques for MCs are known in two different strategies. The first strategy is indirect space vector modulation taking the consideration of a virtual dc link and the second is direct space vector modulation presenting direct conversion [29], [30]. The first research about indirect space vector modulation or it is also known as indirect SVM was proposed by Borojevic *et al* [18], where matrix converter was constructed to combination circuit. This circuit, as it is shown in Fig. 3, synthesis CSI as current source inverter and VSI as voltage source inverter in the connection to a virtual dc link. Three phase inverter stage has six switches, S_7 – S_8 for VSI and also other six switches, S_1 – S_6 for rectifier circuit [15]. Other research about indirect SVM method are also proposed in [2], [13], [16], [18], [20], [31]–[34].

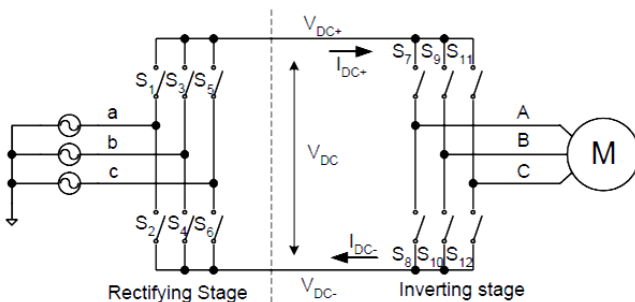


Fig. 3. The equivalent circuit for indirect modulation

Space vector PWM implemented rectifier-inverter in the indirect modulation technique. Three half bridges is not obligatory to follow as an output in this topology, so that only eight switches are possible to apply in the combinations. In Fig. 4(a), this proposed combination can be alienated into six active nonzero output voltage vectors i.e. V_1 – V_6 and two zero output voltage vectors V_0 .

The proposed virtual rectifier avoid an open circuit by using nine switching combinations. In this combination, six active nonzero input current vectors from I_1 – I_6 and three zero input current vectors I_0 are implemented. The implementation scheme is shown in Fig. 4(a). Current I_1 (ab) gives indication that input phase a is bonded to the positive rail of the virtual DC-link V_{DC+} , then the input phase b is tied to the negative rail V_{DC-} . The last connection scheme is shown in Fig. 4(b).

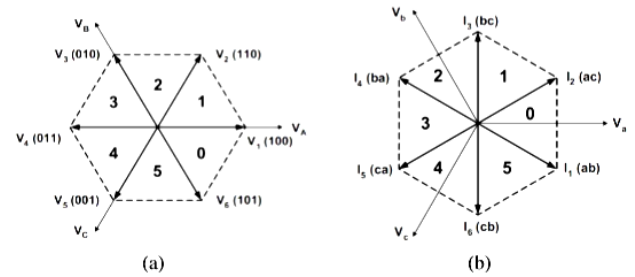


Figure 4: (a) inverter voltage hexagon. (b) rectifier current hexagon.

VI. COMPARISON OF THE MODULATION STRATEGIES

The presentation of modulation strategy discussed in this paper will be compared by considering the following parameters, including: (1) Complexity appeared in theory, (2) current quality at load side, (3) dynamic behaviour and response, (4) resonance of input filter, and (5) performance of the system under unbalanced voltage condition at input side.

A. Theoretical Complexity

In terms of complexity, carrier-based modulation are considered as a simple technique to generate pulses for gate drive in bidirectional power switches, although they are involve many equations[35]. While the SVM method has very complex to implement if we compare this with the carrier-based method or any other control method[5].

B. Quality of Load Current

From several observation in[5], [6], [13], [16], [17], [19], [21], [23], [28], we found that the quality of load current of the carrier-based modulation method and SVM method for MCs is deliver the high quality current to the load. That means quality of load current is not a big problem in the context of MCs.

C. Dynamics Behaviour and Response

The dynamic behaviour and response are important result parameter for some modulation and control method. While the dynamic response of carrier-based modulation method and SVM method is pretty good. Therefore from several observation for dynamic response parameter, we found that the control method like a direct torque control (DTC) and predictive control method has a better result on dynamic response parameter[5],[36].

D. Resonance of Input Filter

The significant issue in MCs when it is implemented and operated is a resonance of the input filter. A very significant impact on the input filter performance is the characteristic of the modulation method[36]–[39], an important observation not previously concerned. As a result, the modulation method works with a fixed switching frequency, in this case SVM method, have made resonance decreased in the input filter. While a Carrier-based modulation method has the input current with strong resonances in the input filter. This behaviour can be significantly improved and it must be considered at input current side.

E. Performance of the System Under Unbalanced Input Voltage Condition.

One of the most significant issues in influencing the performance of MCs is the input voltage condition[40], because of direct power conversion which implies instantaneous power transfer. From several observation through reference[30], [40], [41], [42], we found that the SVM method has a better solution for solving the unbalanced input voltage condition, while the carrier-based modulation has respectable result, although the carrier-based modulation does not need any extra algorithm as the unbalanced condition occurred in input voltage [42].

Based on observations from several references for these modulation methods, we can observe and analysis the comparison of the carrier-based modulation and space vector modulation for IMC. The comparison of these modulation methods has presented in Table I.

TABLE I. Comparison of Modulation Strategies for IMC

Parameter	Modulation method for IMC	
	Carrier-Based Modulation	Space Vector Modulation
Theoretical complexity	very simple	very complex
Quality of load current	good	very good
Dynamic response	good	good
Resonance of input filter	medium resonance	very low resonance
Performance under unbalanced input voltage condition	respectable	very good

VII. CONCLUSION

In recent years the development of MCs area is still interesting, especially in the scope of modulation method for IMC. There are two modulation strategies generally used for MCs namely: carrier-based modulation and space vector modulation. These methods have a different theoretical principles and also different complexity stages.

With the results written in this paper, carrier-based modulation have advantages especially on the level of complexity, where this method has the lowest level of complexity when compared to other methods including the SVM method. While the SVM method has an elegant and powerful solution for IMC. For the future observation, the

comparison and the assessment of the method may include more advanced technical aspect.

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